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RESEARCH PAPER

Status and distribution pattern of coarse woody debris along an altitudinal gradient in Askot Wildlife Sanctuary, Uttarakhand, West Himalaya

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Abstract: A rapid assessment on the status and distribution patterns of coarse woody debris (CWD) was conducted by laying five curvilinear transects (transects A, B, C, D and E; major trails), along an altitudinal gradient starting from 900 to 2 600 m, in three major watersheds (Charigad, Dogarhigad and upper Gosigad) of Goriganga catchment in Askot Wildlife Sanctuary, India. At every 100 m rise in altitude a hectare plot (100 m x 100 m) was selected. Results showed that the percentage contribution by different succession phases was in the decreasing order: phase I > phase II > phase IV > phase III for snags, and phase III > phase II > phase IV > phase I for logs. Snag density in chir pine forest was high in transect A (11 snags·ha^{-1}) at 1 500 m, and the value in rianj oak forest was high in transect B (10 snags·ha^{-1}) at 2 300 m. The total available mass of snags and logs in chir pine forest was 13.9 t, of which snags mass accounted for 41% of the total mass and logs mass for 59%. While the total value was 5.6 t in rianj oak forest, of which snags and logs accounted for 60% and 40% of the total mass, respectively. Moreover, the presence of CWD in the study area if not harvested, would provide a great opportunity to the orchids in future to flourish by providing protection. The high densities of snags and logs in chir pine forest at mid-altitudinal zone led to less species richness and lower density of ground flora as the zone receives more light, accompanying with lower soil moisture, and thus only the dominant species occupy the habitat.

Keywords: Askot Wildlife Sanctuary; chir pine; coarse woody debris; rianj oak; *Pinus roxburghii*; *Quercus lanata*

Introduction

Despite the large amount of organic matter, the coarse woody debris (CWD) still has not been considered as an important feature of a forest ecosystem by the ecologists due to lower concentration of nutrients in cycling and energy flow. However, in fact the input of CWD into the natural ecosystem is a common phenomenon due to the natural catastrophes, such as wind storms, which uproot the tree and blow or break the top of the tree (Falinski 1978; Cline et al. 1980), and landslides due to heavy rains. The CWD includes a wide variety of types, such as snags or logs, chunk of snags or logs (in a particular regime), larger branches and coarse roots or dry attached branches in living trees (Ferris-Kaan et al. 1993). Some of the causes, such as disease, drought, water logging or pollution, as well as shade effect in densely stocked stands of small trees in their early growth period are responsible for death of the individuals (Kirby et al. 1998). The CWD has many crucial ecological functions as habitat for organisms (Harmon et al. 1986). The CWD forms an ideal habitat for many plant taxa, viz. bryophytes, pteridophytes, angiosperms, lichens and fungi, which acts as "Nurse Snag or Log", and thus enriches the plant diversity. Snags provide an abode to many avian for nesting, roosting and vantage point to birds of prey, as well as major sites for the establishment of tree seedlings (on logs) and strengthen the fertility of soil at every succession phase/decay class. Moreover, CWD also plays a major role in energy flow and nutrient cycling in some special ecosystem (Harmon et al. 1986).

In global perspective, many researches have been carried out on various topics related to CWD, including dynamics, decomposition rate, nutrient cycling, water relations, geomorphic functions, animal and insect use and as substrate for fungi and plants (Falinski 1978 & 1986; Triska & Cromack 1979; Cline et al. 1980; Maser & Trappe 1984; Harmon et al. 1986; Spies et al. 1988; Harmon and Chen 1991; Warren and Key 1991; Ferris-Kaan et al. 1993; Freedman et al. 1996; Stevens 1997; Daniels et al. 1997; Frangi et al. 1997; Kirby et al. 1998; Hagan & Grove 1999; McComb & Lindenmayer 1999). In recent years, studies on CWD were mainly focused on the role of CWD in an ecosystem and biogeochemical cycle (Chen et al. 1992; Dai et al. 2002; Zhao et al. 2002; Tang et al. 2003; Timothy and Mark 2004; Zhou et al. 2007). However, only few studies have been

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conducted so far in Himalayan region, in mixed-oak forest in Kumaun (Rikhari & Singh 1998), and in different forests along an altitudinal gradient (1 600−3 400 m) in Garhwal region of Uttarakhand Adhikari (*unpubl.*).

Considering the above gaps in knowledge, the present investigation was attempted to understand the status and distribution patterns of CWD along an altitudinal gradient of 900−2 600 m in a part of Askot Wildlife Sanctuary, Uttarakhand, with the objectives to assess: (1) the status of coarse woody debris along an altitudinal gradient, (2) the status of CWD within and between chir pine (*Pinus roxburghii*) and rianj oak (*Quercus lanata*) forests, and (3) the availability of CWD mass for sustainable use and biodiversity conservation/management strategies.

Materials and methods

Study area

The present study area lies within the Askot Wildlife Sanctuary with an area of 600 km^2 and an elevation range from subtropical (600 m) to alpine, in northeastern part of Kumaun, west Himalaya (6 905 m, Fig. 1). The Goriganga in the study area forms main catchment of the dendritic type of system, running northwestern to southeastern direction in the valley bottom. Several east and west Himalayan species occur in various forest types in the Sanctuary. Currently, there are 20 forest communities totally reported in Kumaun Himalaya (Singh et al. 1994). In the communities reported, there are seven major forest communities, viz. riverine (mixed), chir pine (*Pinus roxburghii*), banj oak (*Quercus leucotrichophora*), rianj oak (*Q. lanata*), kharsu oak (*Q. semecarpifolia*), silver fir (*Abies pindrow*) and birch (*Betula utilis*) in Askot Wildlife Sanctuary (Dhar et al. 1997)..

Methods

Along an altitudinal gradient starting from 900 to 2 600 m, five curvilinear transects (major trails) were laid for intensive study in three major watersheds (Charigad, Dogarhigad and upper Gosigad) of Goriganga catchment, to assess the status and distribution patterns of CWD. All transects passed through different landforms *viz.* forest, forest-agricultural, agricultural-habitation or without habitation, marginal/barren lands. At every 100 m rise in altitude a hectare plot (100 m × 100 m) was selected. Thus the sites along the transects may include exposed sites (on ridge/open slope (aspect) or small elevated vertical ridges) or unexposed sites (depression between close hills). The study area is dominated by two major forest types, *viz.* chir pine forest from 900 m to 1 900 m and rianj oak forest from 2 000 m to 2 600 m. The diagrammatic representation of each transect is shown in Fig. 1 and characteristic features of each transect is given in Table 1. Transects for comparison were also laid next to present study area, i.e. Ghandhura forest.

The structural characteristics of snag/log decay classes are better indicators of time (Daniels et al. 1997). The CWD at different succession phases/decay classes was identified according to previous standard classification (Cline et al. 1980; Sollins 1982; Busse 1994; Kirby et al. 1998) with slight modifications (Table 2). The qualitative (succession phase/decay class) and quantitative (frequency and abundance) data at each site was recorded. The CWD was divided into two types: Fine Coarse Woody Debris (FCWD, <5 cm in diameter) and Coarse Coarse Woody Debris (hereafter referred as CCWD, >5 cm in diameter). Dominant forest species was identified in each site. The coarse woody debris (snags and logs) was assessed based on the classification (Fraver et al. 2002, Table 2) with some minor changes.

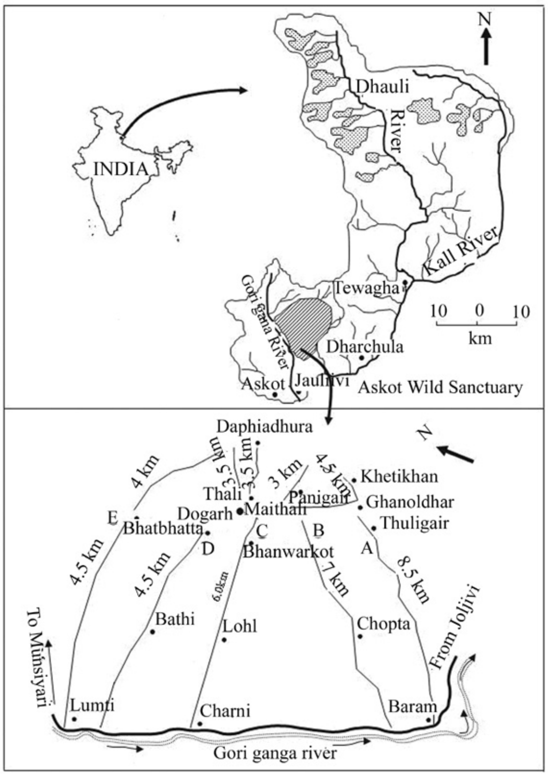

Fig. 1 Map of Askot Wildlife Sanctuary and diagrammatic representation of transects laid in the study area

Table 1. Characteristic features of transects along an altitudinal gradient. SE, south east; SW, south west

Transect	Code	Altitudinal range (m)	Aspect	Village (n)	Watershed
Baram-Ghanoldhar-Khetikhan	A	900-2500	SE-SW	2	Charigad, Gosigad
Chopta-Maitali-Khetikhan	B	900-2500	SE-NW	6	Charigad
Chami-Loll-Maitali-Daphiyadhura	C	900-2600	SW-NW	6	Charigad, Dogarhigad
Lumti-Bathi-Dogarh-Thali-Dhaphiadhura	D	900-2600	SE-SW	5	Dogarhigad
Lumti-Bhatbhatta-Daphiadhura	E	900-2500	SW	3	Dogarhigad

The FCWD was assessed through the observation based on decay classes. It was assumed that the decay classes I, II and III

for logs were equivalent to decay class I of FCWD, and the decay class IV of logs was equivalent to decay class II of FCWD. The FCWD was visually assessed in each site by stack counting (assuming one stack is 25 kg). Morphometric measurements were taken for snags (cbh, circumference at breast height and total height) and logs (circumference at both the ends of a log and the length of a log). The volumes of snags and logs were calculated. Well-established regression equations were used for the calculation of bole, branch and twig mass following Chaturvedi and Singh (1987) for *Pinus roxburghii*, Rawat and Singh (1988) for *Quercus leucotrichophora* and intermediate species, Rana et al. (1989) for *Shorea robusta* and Adhikari et al. (1995) for *Rhododendron arboreum, Lyonia ovalifolia, I. dipyrena*, *Quercus floribunda* and *Symplocos chinensis*.

Table 2. Succession phase/decay class characteristics of snags/logs for identification (modified after Cline et al. 1980; Kirby et al. 1998; Fraver et al. 2002).

Phase/class	Characteristics	
	Snags	Logs
I	recently dead tree with attached branches and twigs	logs with more or less intact bark
II	tree without twigs but with intact bark	logs with loose or without bark and with solid heart wood
III	tree without bark and reduction in surface area (top absent)	bark absent and decomposed sapwood
IV	tree start to decompose and still remain standing (just a straight bole)	sapwood absent and disintegrate heartwood

In the study area, the intermediate species were *Castanopsis tribuloides*, *Engelhardtia spicata*, *Cedrela toona, Alnus nepalensis* and *Mallotus philippinensis*. For succession phase I and II of snags and logs, the masses of bole, branch and twig were calculated. Two curvilinear transects (the same as for present study) on the other side of the river Goriganga, starting from 700 to 1 800 m in exposed and unexposed areas, were laid for comparison with present study area.

Results and discussion

In general, the chir pine forest, rianj oak forest and habitation with agricultural land cover approximately 60%, 30% and 10% of the total study area, respectively. Based on the data reported by Dhar et al. (1997) from the present study area, the total density and basal area of chir pine forest were 616 trees·ha^{-1} and 43.9 m^2·ha^{-1}, respectively, and the values for rianj oak forest were 832 trees·ha^{-1} and 67.7 m^2·ha^{-1}, respectively.

Transect C had the maximum FCWD, followed by transect A, transect D, and transect E, in chir pine forest, while the maximum FCWD in rianj oak forest was in transect C followed by transect D, transect B, transect E and transect A. At altitudes of 1 400 m and 1 500 m all transects had FCWD in chir pine forest, while in rainj oak forest at the altitude of 2 300 m (Fig. 2), FCWD was present in three transects (A, C and E), with high quantity. In all transects the proportion of FCWD for decay class I was similar, except in transect A less FCWD existed mainly due to less number of snags and much dependence of locals for fuel and fodder. The proportion of FCWD for decay class II was similar in transects C, D and E, while the proportion was low in transects A and B. The distribution of FCWD in chir pine forest is directly related with the distribution of CCWD, while in rianj oak forest FCWD was high towards upper region due to natural catastrophe such as high-speed wind in an entire year and reception of more snow fall during winters. The FCWD in exposed site next to the study area, i.e. Ghandhura forest was almost absent; while in the unexposed area next to the study area FCWD was 850 kg in the entire transect starting from 700 m to 1 800 m, which is three times higher than that of the present study. This is largely due to absence of human disturbance, as only primitive human tribe inhabits the area, which is very low in the number of people (< 150) and dense canopy closure. The unexposed site also receives very less sun light due to high-moisture caused slow decomposition and very occasionally local use in the area.

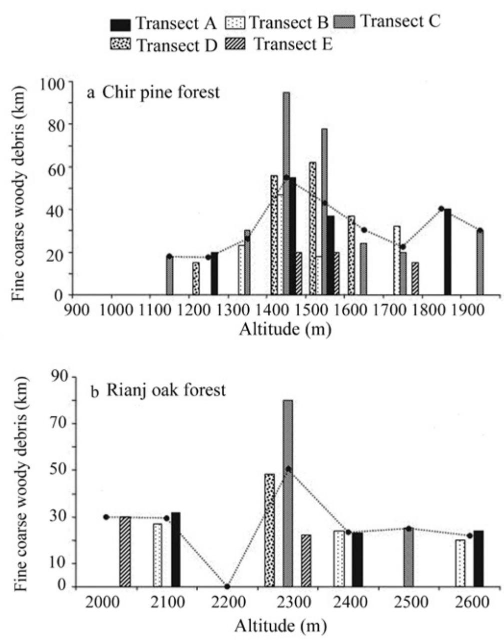

Fig. 2 Fine coarse woody debris along an altitudinal gradient in chir pine forest (a) and rianj oak forest (b). Dotted line shows the average values at each circle.

The average percentage contribution by different succession phases of snags was in the following order: phase I (62%) > phase II (32%) > phase IV (4%) > phase III (1%). The proportion of snags for phase I was higher in all transects than that of other three phases, except for transect B with the highest proportion of 66.7% for phase II (Table 3). The average percentage contribution by different phases of logs was in the following order: phase III (42%) > phase II (29%) > phase IV (22%) > phase I (15%). The average percentage contribution of log's decay class III was the maximum in all transects, while in transect B the proportion of decay class II was the highest (see Appendix I).

Table 3. Percentage contribution (%) of different phases/classes of snags and logs in transects.

Transect	Snags (%)				Logs (%)			
	I	II	III	IV	I	II	III	IV
A	87.0	8.7	0	4.3	9.8	23.0	41.0	26.2
B	25.0	66.7	0	8.3	14.7	41.2	35.3	8.8
C	46.2	46.2	0	0	29.4	23.5	58.8	29.4
D	100	0	0	0	16.0	36.0	40.0	8.0
E	50.0	38.9	5.6	5.6	7.1	21.4	35.7	35.7
Average	61.6	32.1	1.1	3.6	15.4	29.0	42.2	21.6

In all transects, the density of snags was maximum at altitudes of 1 400−1 500 m, which is mainly dominated by chir pine (94%). In chir pine forest, snag density was the highest in transect A (11 snags·ha^{-1}) at 1 500 m followed by transect E (4 snags·ha^{-1}) at 1 400−1 500 m and transects B and D (1 snag·ha^{-1}) at 1 500−1 600 m. In rianj oak forest, the snag density was maximum in transect B (10 snags ha^{-1}) at 2 300 m followed by transect A (5 snags·ha^{-1}) at 2 000 m, transect E (3 snags·ha^{-1}) at 2 600 m, and transect C (2 snags·ha^{-1}) at 2 300 m, while snags were absent in transect D. In contrary to this, the log density had no definite pattern in both the forests. The log density was the highest for both the forests in transect A (13 logs·ha^{-1} in chir pine forest and 6 logs·ha^{-1} in rianj oak forest, respectively). Along an altitudinal gradient, the volumes of snags and logs were both the highest at 1 400−1 500 m in chir pine forest (Fig. 3a), while the volume of snags in rianj oak forest varied with increasing altitudes from 2 000 m to 2 600 m (Fig. 3b). As suggested by Spies et al. (1988), the CCWD is a product of disturbances, therefore its decomposition in physical and biological processes is very complex (Harmon et al. 1986; Mattson et al. 1987), which is affected by wood characteristics, climate and human disturbances etc. (Kaarik 1974; Swift et al. 1979).

The volume of logs in rianj oak forest was exceptionally high at 2 600 m as compared with other altitudes (Fig. 3b). The mass of snags in chir pine forest was quite high at 1 400−1 500 m, while the mass of logs has large variation along the altitudinal gradients from 900 m to 1 900 m (Table 4). The high mass of snags was mainly attributed to branches as at mid-elevation wind velocity is larger in common, and the high mass of logs on both the ends of elevation gradient was mainly due to its non-utilization, as the local people depend on mixed sal forest in lower side and on chir pine-mixed forest in higher side for their resources. According to Harmon and Chen (1991) the accumulation of CCWD affects development of the forest by affecting micro-relief, soils and sediments transport and the distribution and severity of fires (Agee and Huff 1987, Harmon et al. 1986). In general, as compared with the present studied forest, the volume and mass of logs in the adjacent forest, *i.e.* Ghandhura forests were high at 1 800 m in unexposed site and at the altitudes of 900 m to 1 100 m in exposed site. In detail, the volume and mass of logs at 1 800 m were 1.6 times and 8.7 times , respectively, higher in unexposed site of Ghandhura forest than in the present studied forests. However, at 1 100 m the volume and mass of logs were 4.3 times and 1.2 times higher in the present studied forests than in unexposed site of Ghandhura forest, and the values at 900 m were 0.6 times and 13.8 times, respectively, higher for, the Ghandhura forest at exposed site than for present study (average). In contrary to present study, the greater CWD load on northeastern slopes, as the productivity is often greater on slopes with more mesic exposure, has been reported by Gaiser (1951), Hannah (1968) and Auchmoody & Smith (1979), and more fertile north-facing slopes had greater CWD volume and density than that of south facing slopes in an old growth mixed mesophytic forest (McCarthy et al. 2001). Moreover, significant greater CWD mass on moist sites than that of dry sites in *Pinus ponderosa* in Colorado was recorded by Robertson & Bowser (1999), and in *Pseudotsuga menziesii* in western Oregon and Washington by Spies et al. (1988). The increase in volume of CWD along a productivity gradient from southwest Missouri to northeast Indiana (Spetich et al. 1999) was also reflected in the present study.

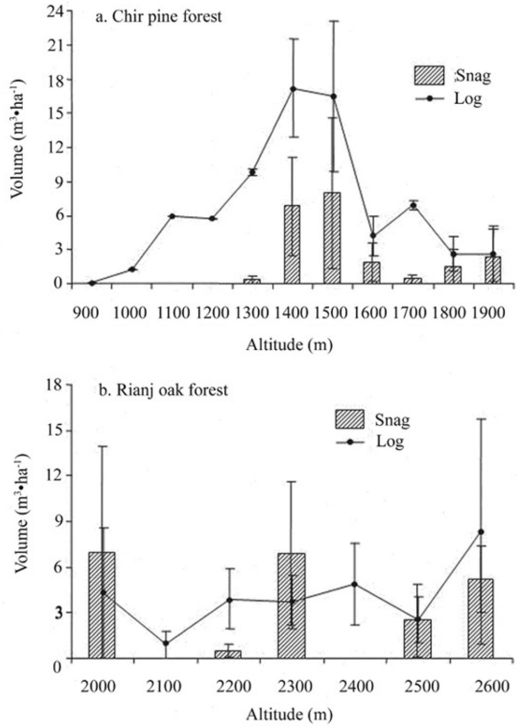

Fig. 3 Snag and log volume at different altitudes in chir pine forest (a) and rianj oak forest (b).

In chir pine forest, the effect of abiotic factors such as fire and wind storms plays a crucial role in enhancing the snags density. Biotic factors (resin taping in past) contribute to the increasing snags density only in a particular altitudinal belt (1 400−1 500 m). The pine patches with large basal area (Naithani, per. comm.) are not affected by wind in lower part of the gradient, while the patches are largely affected by fire in middle part of the gradient. According to Spies and Cline (1988) the CWD mass is much higher in wildfire regenerated stands than that of stands intensively managed for timber production. The chir pine is a fire resistant species but the trees are much susceptible to fall due to resin taping in the past, as the blazes (deep cuts along the tree trunk vertically) are prone to catch fire. The maximum intensity of wind and fire mainly affect the trees on the ridge and the direction and strength of wind storms are being mainly controlled

by the combined effect of slope, steepness, aspect and topographic configuration in the study area. The tree mortality was high on sites where number of blazes was more (6−7) and their size varies from 6−7 cm deep, 10−12 cm wide and 90−100 cm long. However, four blazes (10 cm wide and 70−80 cm long) with shorter freshening cycle produces higher yield of resin (Lohni 1985).

Table 4. Component-wise snag and log mass at different altitudes in chir pine forest (a) and rianj oak forest (b).

Altitude	Snags			Logs		
	Bole	Branch	Twig	Bole	Branch	Twig
			Chir pine forest			
900	-	-	-	41.4±41.4	0.1±0.1	0.1±0.1
1000	-	-	-	228.1±228.1	123.1±123.1	-
1100	-	-	-	590.6±412.1	363.3±234.3	92.0±64.4
1200	-	-	-	106.3±106.3	121.3±121.3	-
1300	93.6±72.2	106.3±82.3	93.6±72.5	453.2±229.1	516.5±261.2	183.5±183.5
1400	587.6±354.5	668.1±404.5	303.0±160.4	589.6±294.0	672.4±335.1	311.8±311.8
1500	968.8±610.1	1054.6±697.7	770.0±641.3	599.7±238.7	683.5±272.6	173.5±173.5
1600	131.5±91.5	149.7±104.4	93.9±93.9	108.6±66.5	123.5±75.7	-
1700	-	-	-	510.9±273.8	577.8±308.8	350.4±175.1
1800	159.8±131.7	181.7±150.0	160.1±132.2	88.1±88.1	100.5±100.5	-
1900	113.5±113.5	129.7±129.7	0	165.5±165.5	188.3±188.3	100.4±100.4
			Rianj oak forest			
2000	424.3±424.3	483.9±483.9	426.7±426.7	150.4±150.4	171.9±171.9	-
2100	-	-	-	146.2146.2	83.2±83.2	-
2200	-	-	-	288.4274.7	167.8±159.0	-
2300	858.1±422.0	475.3±229.1	-	72.672.6	42.8±42.8	-
2400	-	-	-	284.6181.7	158.8±100.5	27.6±27.6
2500	6.5±2.2	2.2±0.9	0.9±0.9	253.5±148.2	131.9±31.2	38.5±31.2
2600	427.1±372.5	228.7±209.7	46.4±46.4	110.5±74.7	58.0±44.1	29.2±18.7

In rianj oak forest, the increase in the snags density not merely depends upon the abiotic factors but also depends on biotic factors, such as extraction of fuel wood, fodder and other uses. It is interesting to note that in rianj oak forest, the dominant species *Quercus lanata* does not have any snag or log in the study area, while other associate species have large snags. The effect of fire intensity is directly related to the inclination and aspect of the hill as well. In transect A the intensity of fire in lower region is high due to its inclination towards southeast aspect, where the wind velocity is maximum through narrow mountains and with steep slopes as in transects C and D. The wind velocity also promotes fire intensity as per terrain features. The intensity of fire was lower at the upper part of transects A and B as well as throughout transect D, because of its undulating terrain. In chir pine forest the wind velocity is high due to open faces towards the river and heavy load of litter. In April the wind storms, hail storms and lightning are the main source of enhancing the CWD in chir pine forest. However, in rianj oak forest the intensity of fire was lower and wind velocity was less as the fact that the ground surface remains mesic under unexposed conditions with depressed terrain. The effect of fire continues up to ridge top on the other side of transects A and B due to steep slope where wind blows from valley bottom to upward directions very rapidly.

The comparison with the forests from different parts of the world (Table 5) suggests that the snag density of chir pine forest in the present study is generally equal to that of the *Pinus radiata* forest (1.0−6.3 snags·ha^{-1}, Baker & Attiwill 1985; Chee 1999) and quite lower than that of *Pinus elliottii* (33 snags·ha^{-1}, Simpson et al. 2000). The snag density of present studied rianj oak and chir pine forests is very much well within the range reported for mixed rain forest (0.5−18.6 snags·ha^{-1}, Grove 2001). The log density of present studied forests coincides with the range reported for broadleaved forest (11−50 logs·ha^{-1}; Kirby et al. 1998). The log mass of chir pine forest is four times higher than that of rianj oak forest, while log mass reported for other forests of the world is on the lower side of the range reported for present study.

In general, chir pine forest grows on dry soil with the deep less than that of rianj oak forest (Singh and Singh 1987). Therefore, chir pine tree and rianj oak tree have shallow and deep root systems, respectively. This is one of the reasons of uprooting of pine tree, while in rianj oak forest uprooting was observed only on those sites where the forest density was low with exposed face. The deep root system helps oak tree for the soil and water conservation. The enrichment of soil through litter is one of the most crucial processes in biogeochemical cycle of forest ecosystem. As the soil fauna (micro-organisms) influence the process of litter decomposition through immobilization (Upadhyay and Singh 1989), and correspondingly the diversity of micro-organisms will also increase with increasing soil nutrient enrichment, which ultimately enhances the biodiversity of the area.

The total available mass (snags and logs) in chir pine forest

(up to the collection range) is 13.9 t, of which the snags accounted for 41% and the logs for 59%. However, in rianj oak forest the value is 5.6 t, of which the snags and the logs accounted for 60% and 40%, respectively. As shown in the above data, the available mass is 2.5 times higher for chir pine forest than for rianj oak forest. The available mass of chir pine forest is more or less similar between low (900−1 300 m) and high (1 600−1 900 m) altitude villages. The chir pine and rianj oak forests are the major source of local inhabitants for fuel wood and the average demand for chir pine and rianj oak is 8.8 and 3.3 kg·household^{-1}·day^{-1}, respectively, as reported by Samant et al. (2000). The available mass of chir pine forest can provide fuel for 354 and 390 days·household^{-1}, respectively, to low and high altitude villagers from the sustenance point of view, however, rianj oak forest for 1 696 days·household^{-1}. It may be one of the reasons of maximum CCWD between 1 400−1 500 m, as the locals use other species for fuel wood purpose.

The present study reveals that the density of snags and logs was high in the mid-altitudinal zone in chir pine forest, while the minimum in mid-altitudinal zone of rianj oak forest. Coarse woody debris is one of the major contributors to the carbon pool of the ecosystem and can act as sink or sources of carbon. In the present study, the four stages of snags and logs represent various seral stages, which govern the distribution and diversity patterns of plants and animals, seedling establishment, physical and chemical properties of soil, water and soil conservation, nutrient cycle and carbon cycle. The high density of snag and log in chir pine forest at mid-altitudinal zone leads to the less species richness and lower density of ground flora as the forest area receives more light, consequently the moisture content of the soil become less and does not give chance to other species to grow and only the dominant species occupy the habitat. However, on the lower and higher side of the altitudinal gradient the species richness and density of ground flora is high due to high moisture content and habitat diversity. In rianj oak forest, species richness and density of ground flora have no correlation with snag and log density. The presence of snags and logs in these forests enhances the diversity of various taxa, especially orchids (Samant et al. 1995), as the orchid diversity is supposed to be the highest in this part of Askot Wildlife Sanctuary.

Further research is needed to develop an integrated comprehensive, multi-dimensional long term study on coarse woody debris, which may help in conservation and management strategies for Askot wildlife sanctuary in a scientific way.

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Appendix I: Decay phases/classes, diameter and number (n) of snags and logs in different transects.

Transect	Species	Snags			Species	Logs		
		Decay class	Diameter (cm±1SE)	(n)		Decay class	Diameter (cm±1SE)	(n)
A	*P. roxburghii*	I	130.7±6.8	20	*P. roxburghii*	I	85.8±29.3	5
	P. roxburghii	II	76.0	1	*E. spicata*	I	92.0	1
	Q. leucotrichophora	II	40.8	1	*P. roxburghii*	II	144.6±13.4	10
	Q. leucotrichophora	IV	96.0	1	*E. spicata*	II	108.0	1
					L. ovalifolia	II	71.0	1
					P. roxburghii	II	292.0	1
					Q. leucotrichophora	III	76.0	1
					L. ovalifolia	III	51.0	1
					P. roxburghii	III	145.4±8.9	22
					P. roxburghii	IV	141.1±8.6	13
					R. arboreum	IV	133.5±24.5	2
					A. nepalensis	IV	56.0	1
B	*P. roxburghii*	I	182.0	1	*P. roxburghii*	I	86.0	1
	Q. leucotrichophora	I	108.5±2.4	2	*S. robusta*	I	73.3±17.5	3
	Q. leucotrichophora	II	34.3±8.6	4	*C. toona*	I	76.0	1
	R. arboreum	II	34.8±3.9	4	*Q. leucotrichophora*	I	14.9±9.1	14
	Q. leucotrichophora	IV	172.0	1	*P. roxburghii*	II	20.0	1
					P. roxburghii	III	145.4±12.9	11
					P. roxburghii	IV	122.3±17.7	3
C	*P. roxburghii*	I	92.0±21.5	6	*P. roxburghii*	I	137.4±16.5	7
	S. cumini	I	68.0	1	*L. ovalifolia*	I	67.0	1
	Q. leucotrichophora	II	189.0	1	*P. roxburghii*	II	80.0	1
	R. arboreum	II	219.0	1	*Q. leucotrichophora*	II	126.4±18.2	5
	Q. leucotrichophora	IV	163.0	1	*R. arboreum*	II	93.5±29.5	2
					P. roxburghii	III	90.8±9.7	8
					Q. floribunda	III	173.3±28.6	7
					Q. leucotrichophora	III	138.5±26.7	4
					R. arboreum	III	42.0	1
					P. roxburghii	IV	96.6±6.9	8
					Q. floribunda	IV	59.0	1
					L. ovalifolia	IV	152.0	1
D	*P. roxburghii*	I	198.0	1	*P. roxburghii*	I	147.3±22.0	3
					R. arboreum	I	97.0	1
					P. roxburghii	II	10.6±1.0	2
					Q. leucotrichophora	II	148.318.4	6
					R. arboreum	II	128.0	1
					P. roxburghii	III	105.0±13.0	2
					Q. leucotrichophora	III	154.7±21.2	7
					R. arboreum	III	137.1	1
					Q. leucotrichophora	IV	127.0	1
					R. arboreum	IV	140.0	1
E	*P. roxburghii*	I	64.8±19.0	8	*R. arboreum*	I	167.0	1
	Q. leucotrichophora	I	215.0	1	*P. roxburghii*	II	102.5±69.5	2
	P. roxburghii	II	165.8±22.9	4	*L. ovalifolia*	II	140.0	1
	E. spicata	II	77.0	1	*P. roxburghii*	III	106.8±8.9	4
	Q. leucotrichophora	II	214.7±2.0	2	*Q. leucotrichophora*	III	189.0	1
	Q. leucotrichophora	III	266.0	1	*P. roxburghii*	IV	78.5±13.5	2
	R. arboreum	IV	69.0	1	*L. ovalifolia*	IV	96.0	1
					R. arboreum	IV	146.0	1
					Q. leucotrichophora	IV	126.0	1